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A COMPARISON OF SEVERAL CLASSES OF AMERICAN WHEATS AND A CONSIDERATION OF SOME FACTORS INFLUENCING QUALITY.[1]

By L. M. THOMAS,

Grain Supervisor, in Charge of Milling and Baking Investigations.

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INTRODUCTION.

The task of placing wheat classification and grading on a scientific basis involves a consideration of two important problems, the first of which is the investigation of the fitness of the several types of wheat for the manufacture of white flour and the adaptation of the flour from these several types to the manufacture of different kinds of bread products. This primarily concerns the division of wheats of distinctly different character into general classes.

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[1] The investigations reported herein were made in the Office of Grain Standardization of the Bureau of Plant Industry, under the direction of Dr. J. W. T. Duvel, Crop Technologist in Charge, in cooperation with the chemical department of the North Dakota Agricultural Experiment Station. Since August 18, 1916, the grain-standardization investigations of the Department of Agriculture have been administered jointly by the Bureau of Plant Industry and the Office of Markets and Rural Organization in connection with the enforcement of the United States Grain Standards Act.

The second problem is the comparative valuation of the wheat within any one class or, in other words, the relative importance of factors usually considered in commercial grading. These factors, briefly, are soundness, general appearance, composition, moisture content, varietal differences, and impurities, especially such impurities as are difficult to remove. In this connection the relation of such determinations as weight per bushel and average weight of kernels to quality naturally forms a part of the study.

Having these problems in mind and recognizing that the only sound basis for the determination of its fitness for the manufacture of flour and a study of the characteristics of the flour produced from it, extensive investigations involving milling tests with wheat and baking tests with the flour have been carried on for several years. A partial survey of the results of this work is presented in the following pages.

FACTORS OF IMPORTANCE IN DETERMINING THE QUALITY OF WHEAT.

MILLING YIELD AND FLOUR COLOR.

The term "milling quality" has a varied meaning, and in speaking of wheat of high milling quality two millers may have very different standards in mind. Broadly speaking, any wheat which will yield a high percentage of white, sound flour is of good milling quality. Flour yield, or the quantity of flour of good color that can be produced from wheat, is always the most important consideration in judging wheat. Other factors are of importance in deciding the purpose for which the flour from a certain kind of wheat is best adapted, but usually play a minor part in determining values.

Flour yield and flour color, or the color of the bread produced from the flour, must always be considered together, as they are closely related in their commercial significance. Yield is the quantitative expression of the amount of flour that can be produced from wheat, while color is the chief factor in determining the grade of the flour and consequently its selling price.

Flour yields in the following pages are expressed as a percentage of straight flour. The term "straight" in this connection has much the same significance as it has commercially, and includes all of the flour usually included in the "Patent" and "Clear" grades.

The color scoring system is based on an arbitrary scale on which the highest markings are 105, but only very exceptional straight flours score over 100. The scoring is decided upon by comparison with loaves from check or standard flours. Straight flour from ordinary sound wheat will score usually between 90 and 100. Flour which will not score more than 50 is of such poor quality that it would be classed with the lowest grade of commercial flours, such as "red dog."

FLOURS OF HIGH AND OF LOW STRENGTH.

The definition given for a wheat of high quality holds good only when no consideration is given to the remarkable variation in the working qualities of different flours in the hands of the baker. Strength may be defined as that quality in flour which enables the baker to produce a loaf of bread of large volume and of good texture by use of the proper ingredients, together with proper mixing, fermentation, and baking.[1] From this definition it will be apparent that strength is of great importance in the making of ordinary fermented bread. For other food products, however, high strength is not required and is not even desirable. This is especially true in the manufacture of products in which chemical leavening agents are used in place of yeast. Low-strength flours are preferable in the making of crackers and practically all pastry, as they yield products which are free from undesirable toughness and, on the other hand, are either flaky, brittle, or crumbly, as the character of the product demands; and this result is attained with a saving in the quantity of lard or other shortening required as compared with what is necessary for stronger flours.

In the manufacture of macaroni and similar products, although strong flours are not necessary, ordinary low-strength flours are not at all suitable. The essential requirements of wheat for making flour for these purposes are that it shall be hard in texture and of such character that it will pulverize into a coarse granular flour, or, as it is more often called, "semolina," and that this be glutenous, or high in gluten proteids. The first of these requirements seems to facilitate the mechanical part of the manufacture, while the second improves the quality of the product by preventing disintegration during cooking.

LOAF VOLUME AND TEXTURE.

This leads to a consideration of the measure of strength in flour. The definition of strength already given mentions two factors as of importance, namely, size and texture of loaf. A measure of the volume of the loaf gives the desired information as to size, and in the following pages this is expressed in cubic centimeters. The figures are comparative, as in every case 340 grams of flour were used for a loaf. It is more difficult to express texture in absolute terms, as it is dependent upon several related considerations. The uniformity, number, and evenness of distribution of cavities are the most important points. For a loaf to be of good texture the walls of the cells should be thin and nearly transparent. To obtain a measure of texture it has been found necessary to resort to an arbitrary scoring system based on the ideal as 100.

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[1] The term "strength" is sometimes considered as meaning the water-absorbing power of the flour, but the definition given above is the one far more widely used at the present time. Some writers use the term "pile" in referring to the shape and texture of the loaf. William Jago and W. C. Jago, in the 1911 edition of their Technology of Bread-Making, define strength as the measure of the capacity of the flour for producing a bold, large-volumed, well-risen loaf. In this definition the term "bold" refers to the external appearance of the loaf and "well-risen" to the texture, but the terms seem to be lacking in definiteness.

In order to demonstrate clearly what is meant by differences in strength as indicated by loaf volume and texture, figures 1 and 2, showing photographs of loaves having a wide range in quality, are introduced here. Figure 1 shows the exterior of loaves having a volume varying from 1,855 to 3,020 cubic centimeters. The volume of the loaves, in cubic centimeters, in order, is as follows: *a*, 2,700; *b*, 1,855; *c*, 2,400; *d*, 3,020; *e*, 2,170. Figure 2 shows another series of loaves in cross section, illustrating differences in texture as well as volume. The volume of loaf *a* is 1,550 cubic centimeters and the texture 84. This is the type of loaf produced from the softest wheats and those of lowest strength. The texture is even, but the cell walls are thick and the bread is solid and heavy. Loaf *b* is a little below average strength for soft wheats, the volume being 1,830

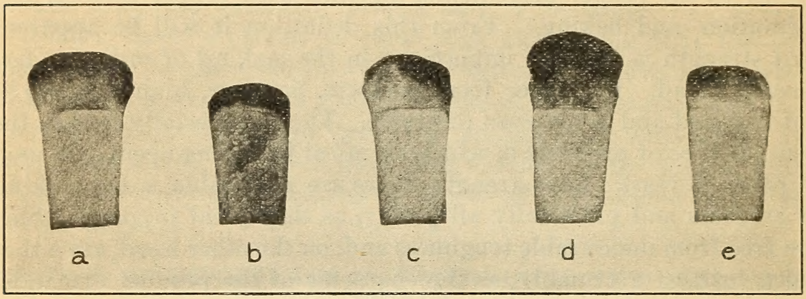

FIG. 1.—Loaves of bread showing a wide range in volume. The volumes in cubic centimeters are as follows: *a*, 2,700; *b*, 1,855; *c*, 2,400; *d*, 3,020; *e*, 2,170.

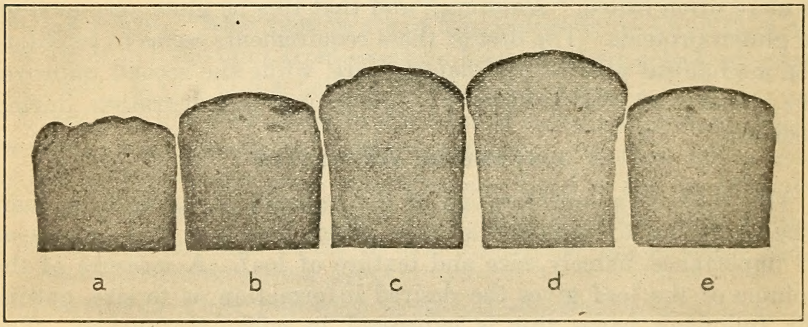

FIG. 2.—Loaves of bread showing a wide range in strength of flour, as indicated by differences in volume and texture. The volumes in cubic centimeters and the texture scores of these loaves are as follows: *a*, Volume 1,550, texture 84; *b*, volume 1,830, texture 90; *c*, volume 2,330, texture 94; *d*, volume 2,660, texture 97; *e*, volume 1,950, texture 88.

cubic centimeters and the texture 90. The texture is uneven, a little coarse, and the cell walls are somewhat thick. Loaves *c* and *d* are of the type ordinarily produced from hard red winter and hard red spring wheats. The volume of loaf *c* is 2,330 cubic centimeters and the texture 94; it is somewhat uneven but the cell walls are fairly thin. Loaf *d* has a volume of 2,660 cubic centimeters and a texture which, although a little uneven, is scored 97, since the cell walls are very thin. Loaf *e* has a volume of 1,950 and a coarse texture, which is scored 88.

WATER ABSORPTION.

Capacity for water absorption is of some commercial importance and is determined by measuring the water added in mixing the dough. It is important because of its relation to the weight of the baked loaf, as will be brought out further in the following pages. It might be considered as one element in the strength of flour if the definition were changed to include, besides requirements for lightness and texture of loaf, a requirement for a high yield of bread per unit quantity of flour.

CLASSES OF WHEAT STUDIED.

In all, five distinct classes of wheats, grown in various sections of the United States, have been studied; but the main part of this report will be confined to the four classes to which more time has been given. The five classes are as follows:

(1) Soft red winter wheat, or "red winter," as it is better known on the market, is the principal class of wheat grown in sections east of the Mississippi River, in the State of Missouri, and in parts of the States adjoining to the west and south.

(2) Hard red winter wheat is grown chiefly in Nebraska, Kansas, and parts of Oklahoma and Montana, although small quantities are grown in the adjoining States.

(3) Hard red spring wheat is grown in North Dakota, Minnesota, South Dakota, and Montana. This wheat is more generally known commercially as northern spring wheat.

(4) Durum wheat is grown in about the same territory as hard red spring wheat and to a limited extent in the southern Great Plains area and Intermountain and Pacific Coast States.

(5) White wheats are grown to a comparatively small extent in some of the Eastern States and more generally in the Intermountain and Pacific Coast States. Only a limited amount of work was done on this class of wheats, and in this report reference will be made only to some factors relating to the quality of the flour produced from them.

There are other classes of wheats, particularly the western red wheats, both spring and fall sown, of which no mention will be made in the following pages.

MILLING YIELD AND RELATED FACTORS.

YIELD OF FLOUR.

As has been said, flour yield is the most important consideration in determining wheat values. Figure 3 affords a comparison of the average flour yields of soft red winter, hard red winter, hard red spring, and durum wheats, and also the extreme and ordinary ranges for each class. While an extreme range in flour yield of about 20 per cent was secured with the durum wheat and a somewhat narrower range for other classes, the ordinary ranges show a variation of only about 10 per cent. Over 90 per cent of the samples of soft red winter and hard red spring and 80 per cent of the durum samples yielded between 65 and 75 per cent of straight flour. The hard red winter samples ranged somewhat higher, as over 90 per cent yielded between 67 and 77 per cent of straight flour.

In average flour yield the hard red winter wheat is about 2 per cent higher than the other classes, between which only small differences are noted, although soft red winter wheat falls slightly below the hard red spring and durum wheats. That this poor showing of the soft red winter wheat is due in part to experimental error is very probable, as this wheat is very difficult to handle in an experimental mill, the flour being soft and fluffy, clinging to the spouts to an unusual degree and causing not only a greater average mechanical loss but also greater moisture losses through evaporation. This is borne out by the figures in Table I, which shows that the average loss was 1.2 per cent greater for soft red winter wheat than for spring wheat. With durum wheat the opposite was true. Durum wheat reduced to a very coarse granular flour which showed practically no tendency to hang to the spouts and dust out.

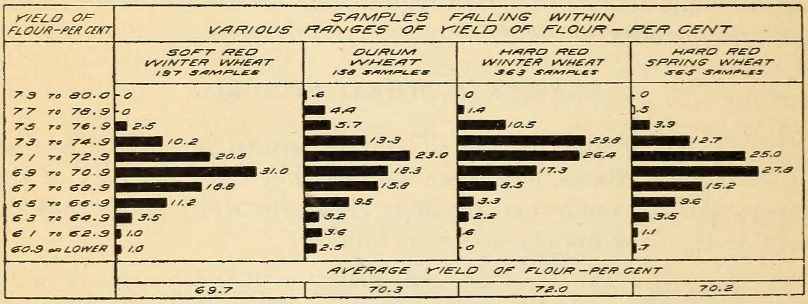

FIG. 3.—Diagram presenting a comparison of the yield of straight flour of four commercial classes of American wheat, showing their general range and the average for each class. The samples used represented the crop years from 1908 to 1913, inclusive, except those of soft red winter wheat, of which only samples of the crops of 1911, 1912, and 1913 are included.

TABLE I.—*Average yield of flour, bran, and shorts of four commercial classes of American wheat and average loss in the milling process.*

Class of wheat.	Number of samples tested.	Milling yields.		Loss in milling.
		Flour.	Bran and shorts.	
		Per ct.	*Per ct.*	*Per ct.*
Soft red winter	197	69.7	27.1	3.2
Durum	158	70.3	28.9	.8
Hard red winter	363	72	26.4	1.6
Hard red spring	565	70.2	27.8	2

It might also be mentioned that the water used in tempering probably had some influence on these figures. With soft-textured wheat like the soft red winter, owing to the tendency toward flaking or flattening out of the particles of endosperm during the grinding process when too much moisture is present, it was not desirable to use a large quantity of water in tempering or conditioning this wheat to toughen the bran previous to milling, while with durum wheat, which is very hard and brittle, the moisture content was raised about 2 per cent on the average by this process. As all yields are figured on the basis of the original cleaned sample, one reason for these differences is apparent. In many cases the durum samples showed a gain in milling due to this added water, but this was very seldom shown with soft wheats.

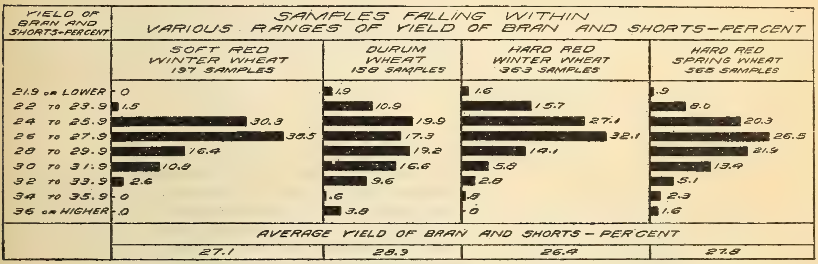

FIG. 4.—Diagram presenting a comparison of the yield of feed (bran and shorts) of four commercial classes of American wheat, showing their general range and the average for each class.

YIELD OF BRAN AND SHORTS.

Figure 4 is a companion to figure 3 and shows in another way the same relation of the milling quality of these four classes of wheat. The importance of a low yield of bran and shorts is evident from the direct relationship of these factors to flour yield.

MOISTURE CONTENT AND FLOUR YIELDS.

As was brought out in the above discussion and in Table I, evaporation during the milling process bears a very important relationship to flour yield. The extent to which evaporation occurs when factors such as humidity, exposure, and the length of the milling process are equal is dependent upon the moisture content of the wheat. This is very clearly brought out in figure 5, which shows the relation between moisture content and flour yield for each of the four classes of wheat under discussion, and also the extreme and the ordinary range and the average moisture content of samples representing each class. It will be noted that with each class the flour yield in a general way varies inversely as the moisture content.

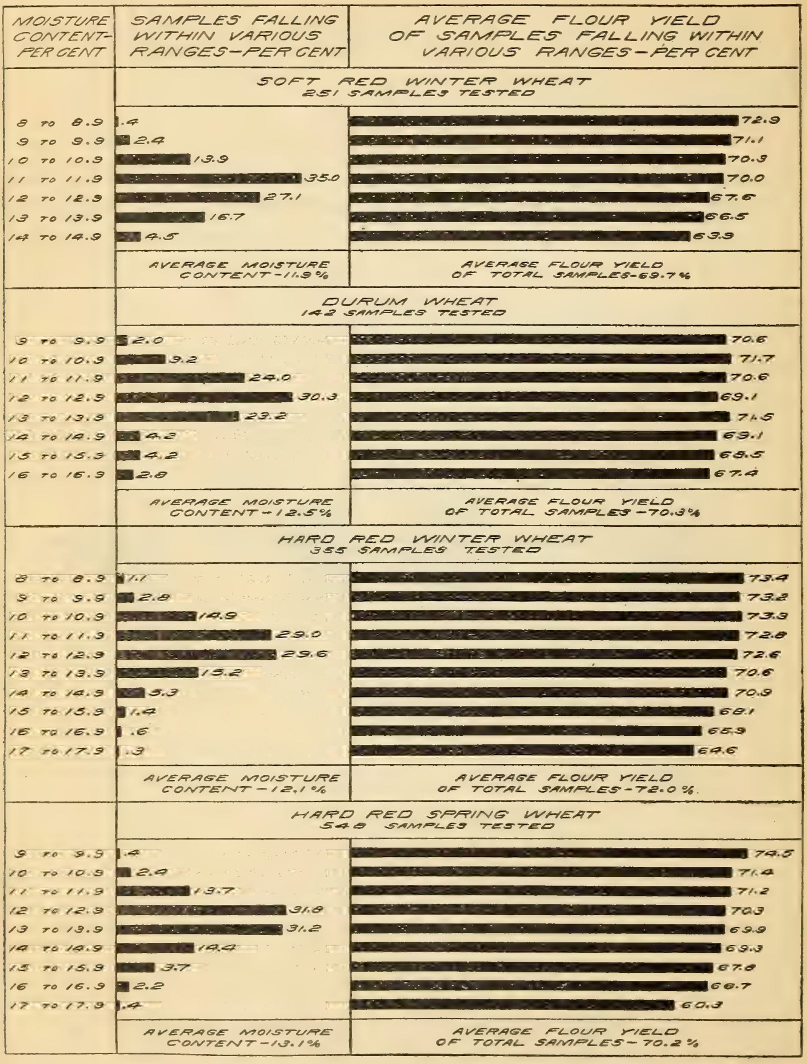

FIG. 5.—Diagram showing the variation in moisture content of the samples of four commercial classes of wheat and the relation of this factor to flour yield.

Figure 6 would seem to prove the hypothesis that the reason for this relationship lies in the evaporation of moisture during the milling process. It shows that there is a very regular increase in milling loss as the moisture content increases.

FLOUR YIELD AND WEIGHT PER THOUSAND KERNELS.

That there might be a relationship between milling yield and average weight of kernels was suggested by several seemingly pertinent facts. Plump or well-filled kernels naturally have a higher weight than shriveled kernels, and that the former are superior in quality as far as milling yield is concerned is evident. Likewise, field damage from sprouting, leaching, and other causes tends to decrease the weight of the kernels somewhat, and these facts bear a direct relationship to milling quality. Figure 7 presents graphically the results of the study of these two factors in relation to each other. It will be noted from this that the weight per 1,000 kernels apparently is not a very good indication of milling yield. Only in the case of badly shriveled samples having an unusually low weight does this factor parallel low flour yield. Two or three factors seem to contribute toward this result. The first and probably most important are varietal differences. Some varieties of wheat have comparatively small kernels, yet give as good a flour yield as wheat of other varieties having much larger kernels. Then, again, seasonal and general environmental conditions cause variations in the size of kernels which do not seem in all cases to be accompanied by corresponding changes in milling yield. One factor related to this is the moisture content, an increase in which also increases the weight of kernels, but this is accompanied by a decrease in flour yield.

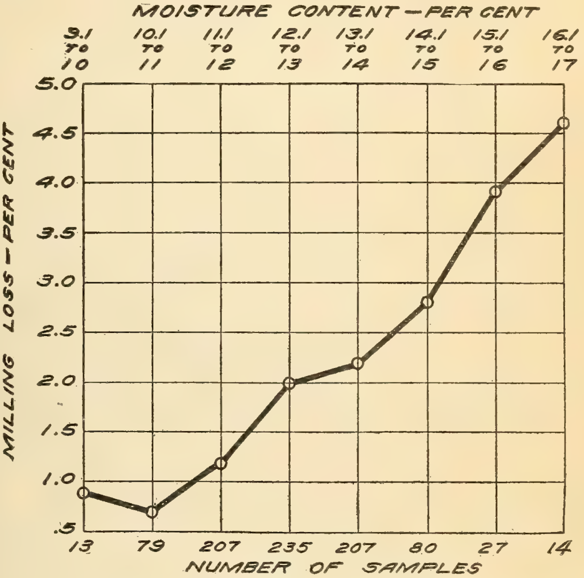

FIG. 6.—Diagram showing the relation between the loss in milling and the moisture content of the wheat.

FLOUR YIELD AND WEIGHT PER BUSHEL.

The value of the "weight per bushel" or "test-weight" determination as a rough means of measuring wheat quality has long been recognized by the grain trade, and requirements relating thereto are made in practically all grading rules. The weight of the measured bushel of pure wheat is dependent upon the specific gravity, shape, size, and uniformity of the kernels. As usually determined, it is affected by impurities, such as weed seeds, dirt, chaff, and other grains. Grade rules in force in a few markets provide that the determination be made on the screened sample, or, in other words, after the larger part of the impurities have been removed. Generally, however, no such rule is observed. The determinations reported here were made with the samples after they had been cleaned and prepared for milling, and the influence of impurities is reduced to a minimum. It will be found that the figures for this reason are a little higher than those ordinarily secured.

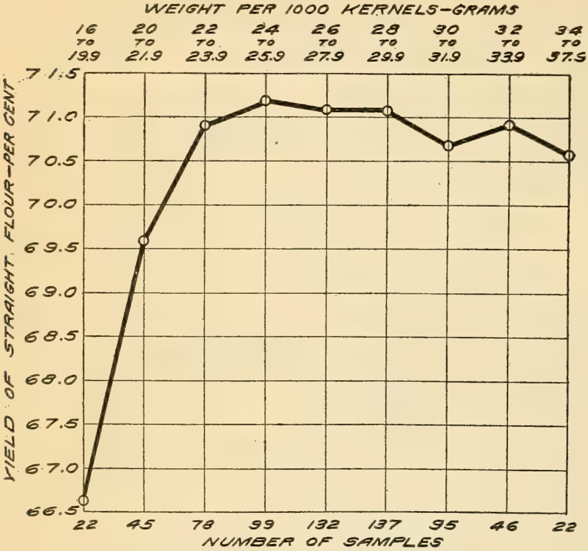

FIG. 7.—Diagram showing the relation between the weight per 1,000 kernels and the flour yield of samples of soft red and hard red winter and hard red spring wheat of the crops of 1911, 1912, and 1913.

Among the factors causing variation in the test weight are shriveled or shrunken kernels, the various forms of damage usually sustained in the field, the moisture content, and varietal differences. The last-mentioned factor is unfortunate and detracts from the value of the test rather than adds to it, as such variations often have little relation to quality. More will be said of this in a following paragraph. All the other factors mentioned bear a direct relation to quality.

That high moisture content is accompanied by low flour yields has been brought out, and as high moisture content is also accompanied by low weight per bushel it is apparent that this determination is of value. Shriveled or shrunken wheat ordinarily gives a low flour yield, because of the low proportion of endosperm to bran and germ, and such wheat is low in weight per bushel. Field damage in various forms seems to bear a direct relation to the quality of wheat, as will be illustrated later, and usually is accompanied by a marked decrease in weight per bushel.

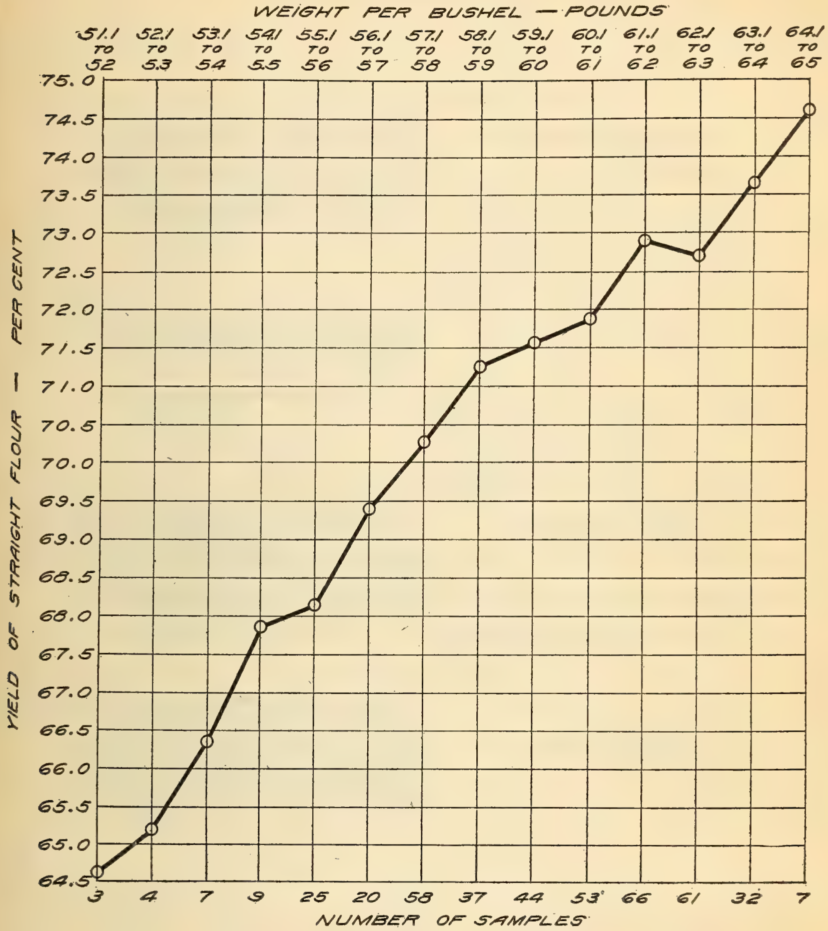

FIG. 8.—Diagram showing the relation between the milling yield and the weight per bushel, as indicated by the results of milling tests with samples of hard spring and hard winter wheat representing the crops of 1911 and 1912.

This brief statement will explain the results graphically presented in figures 8 and 9. In figure 8 are summarized the results of tests with all samples of hard wheats of the crops of 1911 and 1912. The direct relationship between weight per bushel and flour yield is so evident from this diagram that no explanation is needed. In figure 9 more complete data bearing on this relationship are presented.

This diagram shows the variation in weight per bushel of soft red winter, durum, hard red winter, and hard red spring wheats, and also the variation in flour yield for the different ranges in weight per bushel.

It will be noted from figure 9 that as between classes there seems to be little relation between weight per bushel and milling yield. To illustrate: Although the durum samples averaged highest in weight per bushel, the average flour yield is next to the lowest, and spring wheat although lowest in weight per bushel is next to the highest in average flour yield.

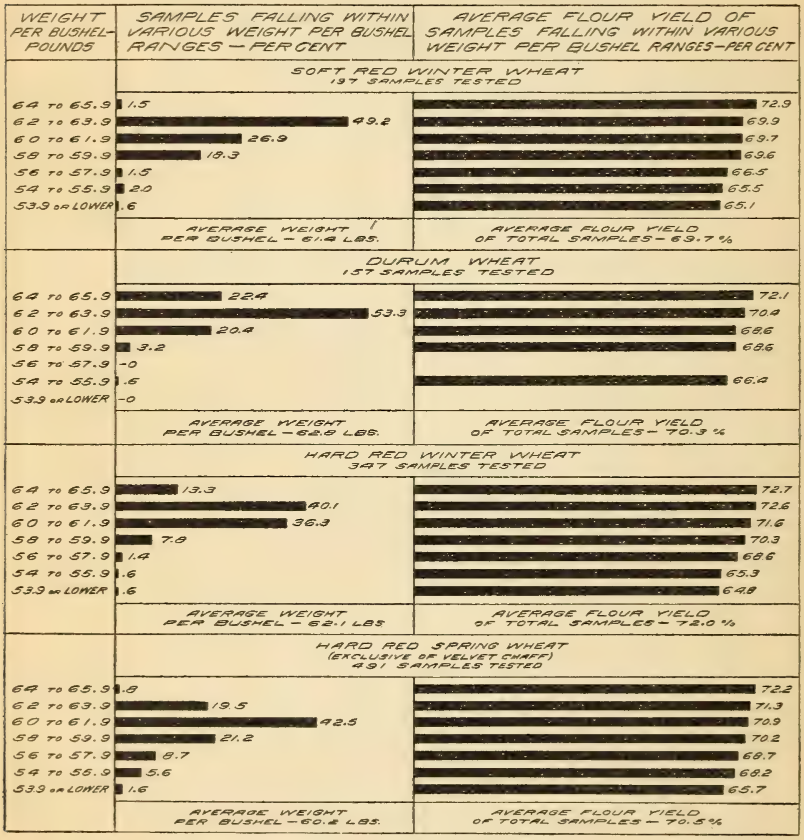

FIG. 9.—Diagram showing the relation between the weight per bushel and the flour yield of four important commercial classes of wheat. The samples represent the crops of 1908 to 1913, inclusive, except those of soft red winter wheat, of which are included samples of the crops of 1911, 1912, and 1913 only.

These variations in the relation of weight per bushel to flour yield among the several classes seem to be associated with differences in the shape, size, and density of kernels and perhaps also the thickness of the bran, any or all of which may be varietal characteristics or the result of environment. Similar variations are found to exist to some degree within each class, and especially is this true of the hard red spring wheat. In this class there are three important varietal groups—namely, Fife, Bluestem, and Preston, or Velvet Chaff.[1]

While between the first two groups no marked differences are noted, the Velvet Chaff wheat, although usually having a high weight per bushel, does not show milling quality superior to the Fife and Bluestem; in fact, it seems to be somewhat inferior. Consequently, when Velvet Chaff is mixed indiscriminately with Fife and Bluestem the weight per bushel is a precarious guide to follow. This is illustrated in figure 10. In the upper part of this diagram all hard red spring samples have been grouped, and it will be noted that there is here no definite relation of flour yield to weight per bushel. When

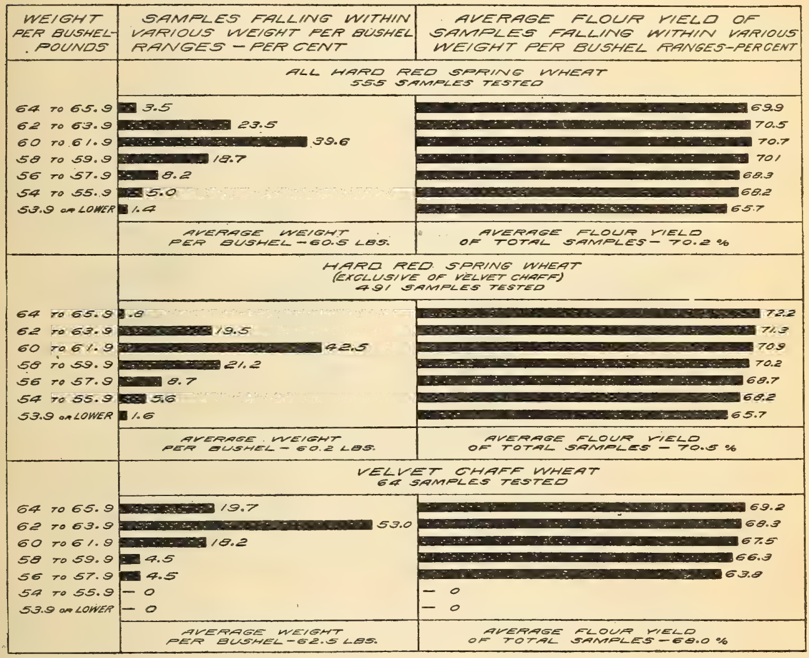

FIG. 10.—Diagram showing the relation between the weight per bushel and the flour yield of hard red spring wheat and the difference in this relation between the so-called Velvet Chaff and the wheat of other varieties. Samples from 1908 to 1913 crops, inclusive.

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[1] The term "Velvet Chaff" as applied to this group of varieties of spring wheat is unfortunate from a botanical standpoint, because of the fact that the chaff or glumes are not velvety or pubescent. This group consists of what are supposedly a number of different varieties, many of which are thought to have originated from the Canadian wheat known as Preston. Nearly all varieties of bearded spring wheat having smooth or glabrous chaff are included. As this paper is written from the commercial standpoint, and as the entire grain trade and most farmers know this wheat as Velvet Chaff, this designation for this variety group will be adhered to in the following pages; but it should be borne in mind that the term Preston is preferable from a technical standpoint.

these samples are separated and the data compiled in a similar manner, however, the reason for this seeming inconsistency in results is apparent.

First, the high percentage of the samples of Velvet Chaff having a high test weight, as compared with the other varieties of spring wheat will be noted and then the lower average flour yield for each range in weight per bushel. These facts illustrate the necessity of care in interpreting the weight-per-bushel determination as applied to wheat of different varieties.

It should also be borne in mind that tests with individual samples do not show the same regularity as is suggested by the averages shown in these illustrations, and the test weight should in all cases be considered in conjunction with other factors, such as moisture content and soundness, of which more will be said later.

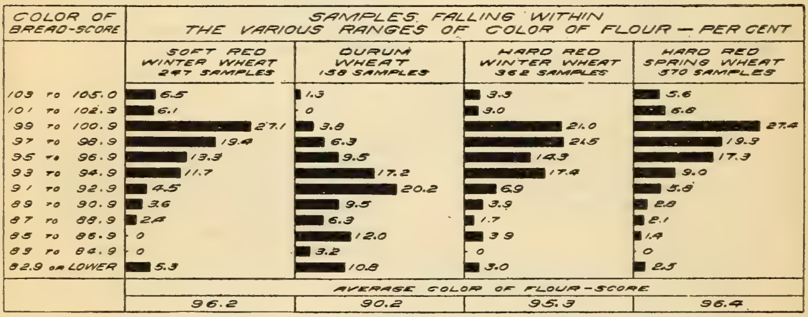

FIG. 11.—Diagram presenting a comparison of the color score of the bread made from five classes of wheat, showing variations, extreme ranges, and averages.

COLOR OF FLOUR AND BREAD.

The importance of a consideration of the color of flour or bread made of flour in connection with milling yields has been mentioned. Commercially, because of the popular demand for white bread, flour color has come to be one of the most important considerations in buying and selling this product. The question naturally arises as to whether there is any general difference in the color of flour of the wheat of the several classes. Figure 11 presents data which will afford a fairly satisfactory answer to this question. The arrangement of this diagram gives an idea of the ordinary ranges in color of the bread from each class, and it will be observed that very little difference is apparent between the classes except in the case of durum wheat. The typical flour from this wheat varies in color from a pronounced creamy white to what might be described as pale yellow.

The comparison shown in figure 11, however, does not tell the whole story, as there are variations in color that can not be expressed by a score. For example, under this system two flours may score the same, though one may be creamy while the other is a grayish white. In order to determine to what extent these color tints are characteristic of any one class, notes relative to them were made on all samples of the crops of 1912 and 1913. A summary of these observations is made in Table II. In this table the samples are classified under two headings, the first including all samples entirely free from creamy or yellow tints, being either pure white or grayish, and the second including samples having a distinctly creamy or yellow tint, as well as cloudy or creamy gray samples. Table II shows that all of the durum wheats fall under the second heading. In the other classes of hard wheats the creamy tints predominate to a less extent, while in the soft red wheats the pure white and gray tints predominate. Old or weathered wheat yields flour with a less pronounced creaminess, and this will account for part of the variation among the hard red wheats. There is also some varietal difference, especially among the hard red spring wheats. Bluestem and Velvet Chaff wheats usually yield flours of a pronounced creamy tint, while the Fife flour tends more toward pure white or grayish white. With the soft red winter wheat the creamy tint ordinarily is absent or not very pronounced, although some varieties seem to differ in this respect, as with other classes.

TABLE II.—*Relative dominance of various color tints of the flour of four commercial classes of wheat, samples of the crops of 1912 and 1913 being used.*

Class of wheat.	Number of samples.	Proportion of samples yielding flour of various color tints (per cent).	
		White to gray, with no marked creamy or yellow tint.	Creamy to yellow (cloudy or creamy gray included).
Durum	49		100
Hard red winter	116	22.4	77.6
Hard red spring	210	30.5	69.5
Soft red winter	90	81.1	18.9

RELATION OF YIELD AND COLOR TO TEST WEIGHT AND SOUNDNESS.

The unavoidable relation between flour yield and flour color in milling makes it important that the diagrams already discussed, showing the relation of flour yield to test weight, be supplemented by a study in which the color of the flour is taken into consideration. This has been done in Table III in connection with a study of the relation of these factors to soundness.

Considering only that part of Table III which relates to weight per bushel, it is apparent that although the relation of this factor to flour yield is quite evident in the diagrams previously shown, this is not true of flour color except with wheat which is fairly low in test weight and then the color falls somewhat lower than with the heavier wheat. This holds true with all three classes of wheat with which this comparison was made.

This table is arranged to bring out such connection as may exist between the percentages of sound wheat and flour yield and color. By percentage of sound wheat is meant that portion of the sample remaining after all damaged kernels, seeds, dirt, and other grains have been removed. As in these studies the analyses were made on samples prepared for milling and after most of the impurities, such as seeds, dirt, and other grains, had been separated, the main factor to be considered is damage, other determinations averaging so low as to be almost negligible.

An analysis of Table III from this standpoint reveals a direct connection between the flour yield and the percentage of sound wheat. With all three classes there is a fairly regular decrease in flour yield as the percentage of sound wheat decreases.

TABLE III.—*Relation of weight per bushel and soundness of wheat to flour yield and color of bread in hard red spring, hard red winter, and soft red winter wheat of the crops of 1911, 1912, and 1913.*

Class of wheat and ranges in weight per bushel (pounds).	Ranges in percentage of sound wheat.																	
	95 to 100.			90 to 94.9.			85 to 89.9.			80 to 84.9.			79.9 or less.			Average of all.		
	Number of samples.	Flour yield.	Color of bread.	Number of samples.	Flour yield.	Color of bread.	Number of samples.	Flour yield.	Color of bread.	Number of samples.	Flour yield.	Color of bread.	Number of samples.	Flour yield.	Color of bread.	Number of samples.	Flour yield.	Color of bread.
Hard red spring:		*P.ct.*			*P.ct.*			*P.ct.*			*P.ct.*			*P.ct.*			*P.ct.*	
64 to 65.9....	2	72	100	3	73.3	92.3	....	.....	....	....	.....	....	....	.....	....	5	72.8	95.4
62 to 63.9....	35	71.5	98	12	70.9	96.5	5	72.2	97.2	....	.....	....	....	.....	....	52	71.4	97.5
60 to 61.9....	24	71.6	96.5	34	71.1	96	18	71.1	94.4	6	71.8	95	....	.....	....	82	71.2	95.6
58 to 59.9....	8	70.8	99.2	16	71.5	95.2	4	70.1	97.7	9	70.9	88	3	65.7	99.3	40	70.5	94.9
56 to 57.9....	3	67.4	99	....	.....	.....	4	68.7	95	2	68.7	95	5	67	88.4	14	67.1	93.5
54 to 55.9....	....	.....	.....	6	65.9	97	....	.....	....	2	67	92	4	66.5	91	12	66.3	93.3
Average...	72	71.3	97.7	71	70.9	95.9	31	70.8	95.3	19	69.6	91.3	12	66.3	91.8	205	70.6	95.7
Hard red winter:																		
64 to 65.9....	20	72.8	97	13	73.2	93.5	....	.....	....	1	74.6	97	1	71.1	99	35	73.1	95.2
62 to 63.9....	25	73.7	95	24	73.5	94.6	19	72.5	94.7	6	72	97.5	4	72.2	97.8	78	73.2	95.1
60 to 61.9....	4	72.4	98	8	72.0	94.7	7	71.3	96.6	8	70	95.8	7	70.3	94.9	34	71.1	96
58 to 59.9....	1	73.1	94.5	....	.....	.....	....	.....	....	2	67.3	96	4	69.9	94.6	7	69.6	95
56 to 57.9....	....	.....	.....	....	.....	.....	2	69.3	94.5	....	.....	....	1	66.9	94	3	68.5	94.2
54 to 55.9....	....	.....	.....	....	.....	.....	....	.....	....	1	63.8	91	1	68.8	89	2	66.3	90
Average...	50	73.2	96.3	45	73.2	94.3	28	72.2	95.2	18	70.7	96	18	69.1	95.4	159	72.3	95.3
Soft red winter:																		
62 to 63.9....	17	70.3	95.8	14	69.6	95.6	6	70.6	93.4	....	.....	....	....	.....	....	37	70.1	95.4
60 to 61.9....	18	69.6	98.2	20	69.8	97.6	17	69.1	95.7	9	69.5	93.7	2	67.1	97	66	69.5	96.7
58 to 59.9....	2	70.4	79	2	64.2	100	6	70.2	94	8	69.3	92.8	2	67.9	91	20	69	92.3
56 to 57.9....	....	.....	.....	....	.....	.....	....	.....	....	....	.....	....	2	60.2	84.3	2	60.2	84.3
54 to 55.9....	....	.....	.....	....	.....	.....	2	65.7	95.1	....	.....	....	1	64.4	89	3	65.3	93.1
52 to 53.9....	....	.....	.....	....	.....	.....	....	.....	....	....	.....	....	1	65.1	75.3	1	65 1	75.3
Average...	37	69.9	96.1	36	69.4	97	31	69.2	95.3	17	69.4	93.3	8	65	88.6	129	69.3	95.3

With regard to color, the relation is not so plain. With hard red spring wheat the color seems to vary somewhat with the percentage of sound wheat, but with the other classes there is no great regularity so far as the averages are concerned.

A further analysis of Table III reveals the greater value of test weight and percentage of sound wheat in judging quality when these two factors are considered together. It will be noted that the wheat of highest quality from the standpoint of yield and color is both high in test weight and in percentage of sound wheat and that the wheat of lowest quality is low both in test weight and in percentage of sound wheat. On the other hand, these figures would seem to indicate that a sample which is low in test weight still gives a fairly high yield of good-colored flour provided it is sound. They would also seem to indicate the converse of this, that a sample low in percentage of sound kernels but high in test weight may be of fairly good quality as far as yield of flour and color are concerned, which indicates that the percentage of unsound wheat is not always an absolute measure of the extent of damage.

INSEPARABLE FOREIGN MATERIAL, FLOUR YIELD, AND COLOR OF BREAD.

In most of the samples milled, even after cleaning and scouring, there remained small percentages of weed seeds, dirt, chaff, and other grains which were ground when the wheat was milled. With the wheat of all classes except the spring wheat, this was such a small amount in the average sample as to be almost negligible. With spring wheat, foreign matter consisting of a variety of weed seeds and other grains, particularly wild oats, was present in amounts sometimes ranging higher than 1½ per cent. The only noticeable effect of this material on the milling quality as revealed by a study of averages is a reduction of milling yield, as is evidenced in Table IV. This is what would be expected, only small quantities of these substances getting into the flour, as they go largely into the bran and shorts. No effect on the color of flour or bread is apparent from these figures. The effects of specific impurities, such as rye, corn cockle, kinghead, and vetch, have been described by R. C. Miller[1] and investigations along this line are being continued.

---

[1] Miller, R. C. Milling and baking tests of wheat containing admixtures of rye, corn cockle, kinghead, and vetch. U. S. Dept. Agr. Bul. 328, 24 p., 10 fig., 2 pl. 1915.

TABLE IV.—*General effect of small quantities of inseparable material (other grains, seeds, dirt, and chaff) on yield of flour and color of bread made from hard red spring wheat of the crops of 1911, 1912, and 1913, inclusive.*

Inseparable material.	Number of samples.	Flour yield.	Color of bread.
Range (per cent):		*Per cent.*	*Score.*
0.5 or less	178	71.3	94.7
0.6 to 1	40	70.7	97.1
1.1 to 1.5	34	69.6	96.1
1.6 or higher	30	69.4	95.3

FLOUR STRENGTH.

COMPARISONS OF LOAF VOLUME.

The term "strength" as applied to flour has been defined and its significance discussed, as have also the two factors of loaf volume and texture, which in this bulletin are considered as a measure of strength. In figure 12 a comparison is made of loaf volume determinations of five classes of wheat, including soft white wheat, with which a comparatively small number of tests were made. This diagram is so arranged as to show the extreme and ordinary ranges for each class, as well as the average, maximum, and minimum loaf volume. From the data here presented it will be seen that the soft white wheats are as a class lowest in strength, soft red winter coming second, with durum, hard red winter, and hard red spring wheats following in order of increasing loaf volume.

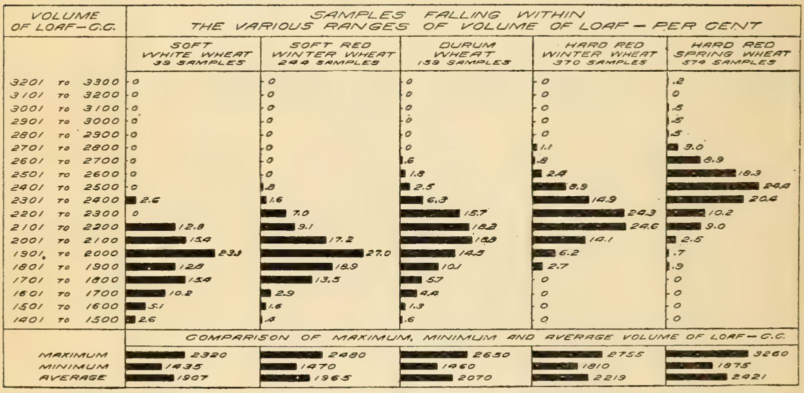

FIG. 12.—Diagram presenting a comparison of the strength of the flour (as indicated by loaf volume) from the five principal classes of wheat, showing variations and averages for each class.

The ordinary range in loaf volume for the soft wheats is from 1,700 to 2,200 cubic centimeters, for durum 1,800 to 2,300, for hard red winter 2,000 to 2,500, and for hard red spring wheat 2,100 to 2,700 per 340 grams of flour. The extreme ranges in loaf volume, as indicated by maximum and minimum, are 1,435 to 2,320 cubic centimeters for the soft white wheat, 1,470 to 2,480 for the soft red winter, 1,460 to 2,650 for the durum, 1,810 to 2,755 for the hard red winter, and 1,875 to 3,260 for the hard red spring wheat. The figures show great variation, which is the result of growing these wheats under a wide range of conditions of soil and climate. In a general way the data gathered from year to year indicate that unfavorable climatic conditions during the later part of the growing season tend to produce the strongest wheats. This is illustrated with the hard red spring wheat of the years 1911 and 1912. In 1911 the latter part of the season was unfavorable and much shrunken wheat, low in flour yield, was the result. Much of the wheat of that year, however, was of exceptional strength. The following year (1912) the opposite was true. Unusually favorable conditions resulted in well-developed wheat high in flour yield, which was, however, of very low average strength for spring wheat.

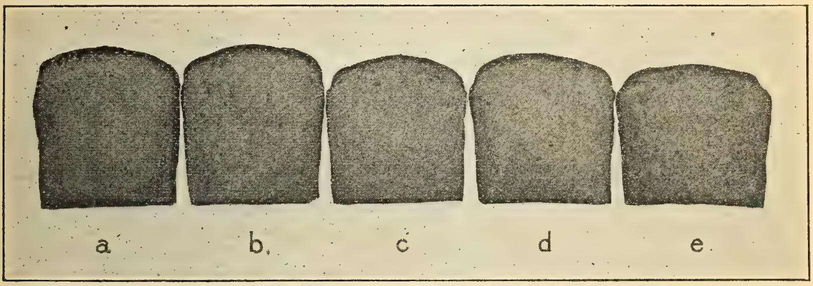

FIG. 13.—Cross sections of loaves of bread made from wheat grown near Shelbina, Mo., showing a considerable range in the quality of low-strength wheat. Loaf *a*, soft red winter wheat, with a volume of 1,935 cubic centimeters and a texture of 94.5; *b*, hard red winter wheat (Turkey), volume 2,075, texture 95; and *c*, *d*, and *e*, soft red winter, with volumes of 1,815, 1,785, and 1,715 and textures of 91.5, 92, and 89, respectively.

One fact clearly brought out by figure 12 is that there is no hard-and-fast line between the various classes, so far as strength is concerned, because of the wide range found in each. When averages are considered, however, differences of considerable magnitude are observed. Soft white and soft red winter are most alike, the average loaf volumes being, respectively, 1,907 and 1,965 cubic centimeters. Durum wheat is a close third, with a volume of 2,070 cubic centimeters, although the flour from this wheat differs in other respects, particularly in color, as was shown in figure 11, and in composition, as will be shown later. Hard red winter and hard red spring wheats have average volumes of 2,219 and 2,421 cubic centimeters, respectively, which shows for these two classes considerable superiority over the others in strength of flour. It shows also that in strength of flour the spring wheat leads the hard winter by a good margin.

Figures 13, 14, 15, and 16, reproduced from a series of photographs, will help to visualize these differences. Figure 13 shows several loaves of bread made from samples of soft red winter wheat and one of hard winter wheat, all of which were grown in the same locality in the State of Missouri. Loaf *a* is from a sample of soft red winter wheat, and its volume of 1,935 cubic centimeters is about the average for this class; loaf *b* is from a sample of hard red winter wheat of low strength, the volume being recorded as 2,075 cubic centimeters; while loaves *c*, *d*, and *e* are from samples of soft red winter wheat which were somewhat below the average strength, the volumes being 1,815, 1,785, and 1,715 cubic centimeters, respectively.

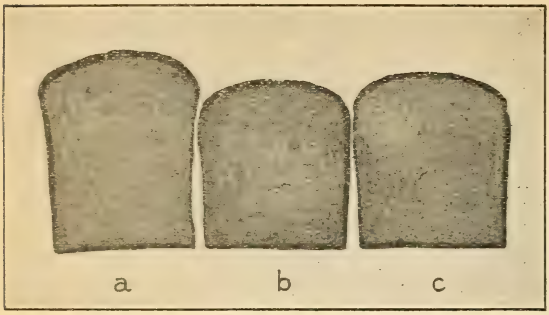

FIG. 14.—Cross sections of loaves of bread made from a high-strength hard red winter wheat and two soft red winter wheat samples of about average strength for this class. Loaf *a*, hard red winter, volume 2,445 cubic centimeters, texture 96; *b*, soft red winter, volume 1,950, texture 88.5; and *c*, soft red winter, volume 1,960, texture 89.

In figure 14 loaf *a* is from a sample of hard red winter (Turkey) wheat which is considerably above the average for this class; in fact, its volume of 2,445 is about the average for spring wheat. Loaves *b* and *c* are from soft red winter samples and are very close to the average volume for this class.

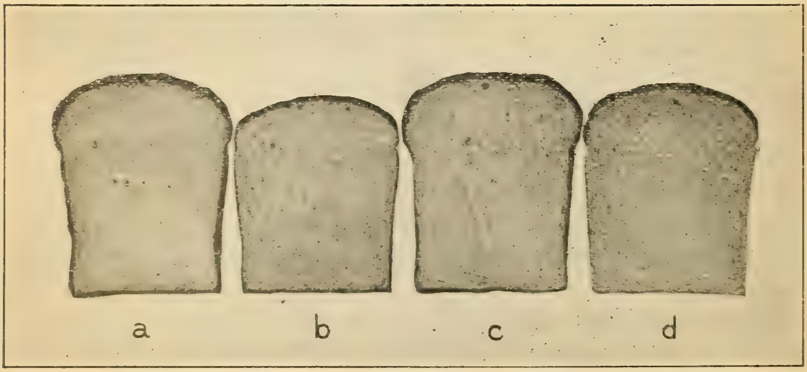

FIG. 15.—Cross sections of loaves of bread made from hard red spring and hard red winter wheat. Loaf *a*, hard red spring, volume 2,615 cubic centimeters, texture 95.5; *b*, hard red winter, volume 2,240, texture 94.5; *c*, hard red spring, volume 2,720, texture 94.5; *d*, hard red winter, volume 2,460, texture 94.

Figure 15 affords a comparison of loaves from hard red winter and hard red spring wheat. Loaves *a* and *c* are from hard red spring wheat and are considerably above the average, their volumes being 2,615 and 2,720 cubic centimeters, respectively. They represent, however, the results commonly attained with the stronger wheats of this class. Loaves *b* and *d* are from hard red winter samples. The volume of *b* is 2,240 cubic centimeters, which is about the average for this class, and the volume of *d* is 2,460 cubic centimeters, which considerably exceeds the average for this class; in fact, it is a little above the average for hard red spring wheats. It represents, however, the common type of loaf produced from the stronger hard red winter wheats.

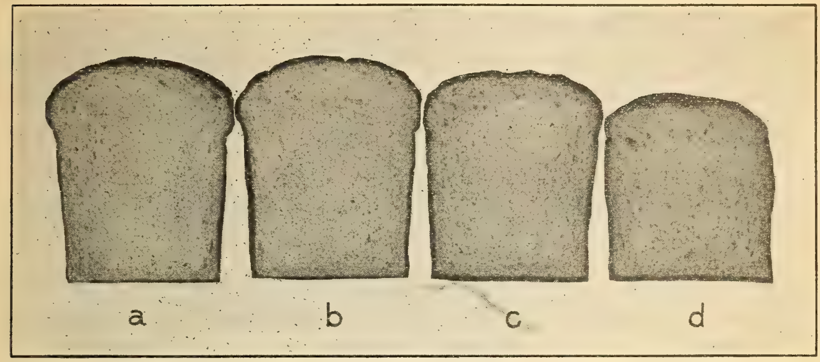

FIG. 16.—Cross sections of loaves of bread, showing a considerable range in the strength of hard red spring wheat and making a comparison of this class with durum wheat. Loaves *a*, *b*, and *c*, from hard red spring wheat and having volumes of 2,520, 2,565, and 2,385 cubic centimeters and textures of 92, 95, and 94.5, respectively; *d*, from durum wheat, having a volume of 1,955 and a texture of 93.5.

Three loaves from hard red spring (*a*, *b*, and *c*) and one from durum (*d*) are shown in figure 16. The volumes are, respectively, 2,520, 2,565, 2,385, and 1,955 cubic centimeters; the first two being above and the last two somewhat below the averages for their respective classes.

COMPARISONS OF TEXTURE.

Before going farther with the discussion of strength, the related factor of texture should be considered. Comparisons of texture similar to those of loaf volume are made in figure 17. As the texture scoring system was not used until 1911, fewer samples were available in compiling this diagram, and it was necessary to omit the white wheats. In a general way the variations in texture parallel

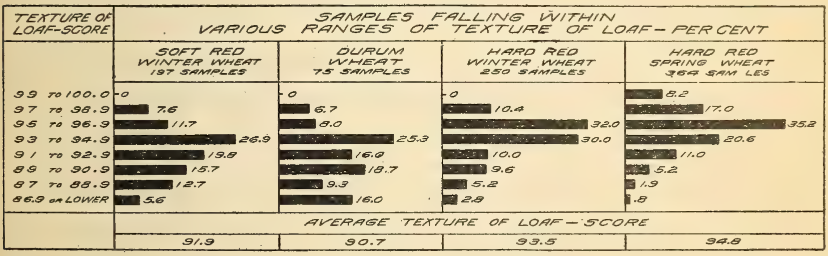

FIG. 17.—Diagram presenting a comparison of the texture of the bread from four classes of wheat, showing their range and the average for each class. Samples from the crops of 1911 to 1913, inclusive.

those in loaf volume, although the differences are not so marked. The average variation in texture between the several classes is largely an indication of differences arising from the number of cavities in the loaf, which is clearly related to the thickness of the walls of these cavities and consequently to the character of the crumb. When the walls of the cavities are very thin the bread is elastic and yielding to the touch, does not crumble easily when cut into thin slices, but is nevertheless tender and free from toughness. Bread with thick cell walls may be brittle, or very crumbly and harsh to the touch when cold, or rubbery and lacking tenderness. Soft wheats tend toward the former, while the very hard wheats of poor quality tend toward the latter condition.

RELATION BETWEEN CRUDE PROTEIN IN WHEAT AND THE STRENGTH OF FLOUR.

The strength of wheat flour apparently bears a very intricate relation to its composition. The physical properties of the proteins of the wheat kernel have long been known to be chiefly responsible for those characters of wheat flour which differentiate it from the flour of other cereals with regard to its ability to retain the gas produced by yeast fermentation.

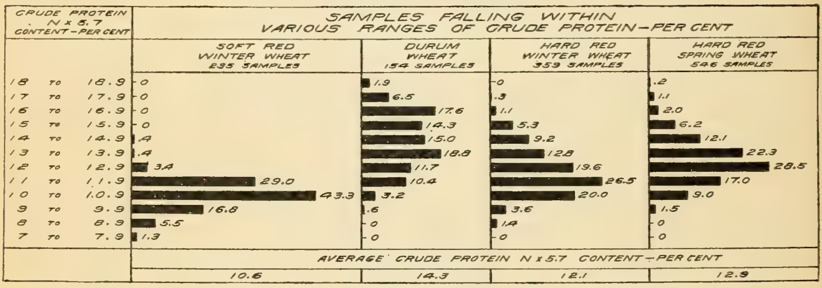

FIG. 18.—Diagram showing the variations in crude protein of four classes of wheat. Samples from the crops of 1908 to 1913, inclusive.

Figure 18 shows graphically the ranges and averages of the crude protein content of soft red winter, durum, hard red spring, and hard red winter wheats. With soft red winter wheat the extreme range is from between 7 and 8 to between 14 and 15 per cent, nearly 90 per cent of the samples, however, falling between 9 and 12 per cent, the average being 10.6 per cent. This average is 1.5 per cent lower than the next highest, which is hard winter wheat. The crude protein content of durum wheat averages 14.3 per cent and the extreme range is from 9 and 10 to between 18 and 19 per cent, with about 88 per cent of the samples falling between 11 and 17 per cent.

Figure 19 shows the relation between the total crude protein of wheat and the strength of the flour within the three classes of common wheat under discussion.

This shows a general increase in strength with an increase in protein content, the only exception being with hard spring wheat having a crude protein content of over 15 per cent. Between the lower percentages of protein wider variation in volume is noticeable with all classes than between the higher percentages. In fact, many samples having a very high protein content are lower in strength than those having a medium content.

This exception is an illustration of the fact that total crude protein is not always an indication of strength due apparently to differences in the composition or properties of the gluten protein or, as has been shown by the number of investigators, to the presence or absence of associated inorganic substances.[1] In this connection men-

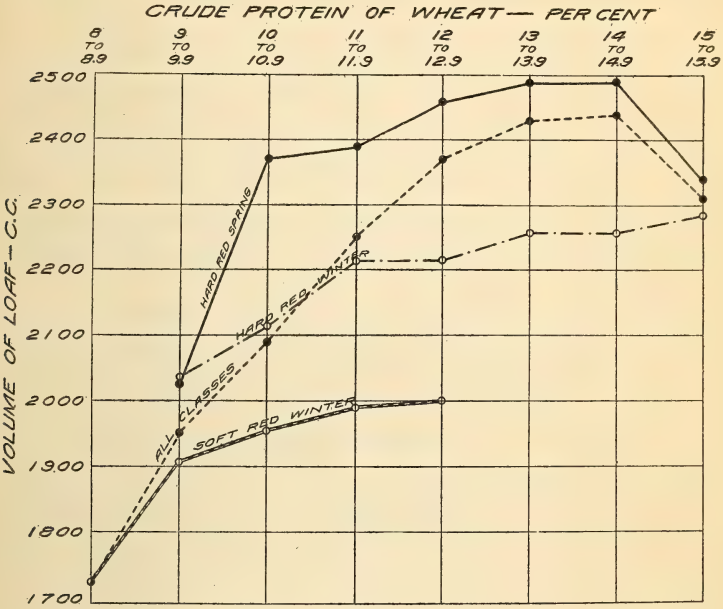

FIG. 19.—Diagram showing the relation between the protein content and the loaf volume of soft and hard red winter and hard red spring wheat. Samples from the crops of 1909 to 1913, inclusive.

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[1] Guthrie, F. B. The absorption of water by the gluten of different wheats. *In* Agr. Gaz. N. S. Wales, v. 7, pt. 9, p. 583–589. 1896.

Fleurent, E. Sur une méthode chimique d'appréciation de la valeur boulangère des farines de blé. *In* Compt. Rend. Acad. Sci. [Paris], t. 123, no. 19, p. 75–758. 1896.

Snyder, Harry. The proteids of wheat flour. *In* Minn. Agr. Exp. Sta. Bul. 63, p. 519–533. 1899.

Shutt, F. T. The relationship of composition to bread-making value. *In* Canada Cent. Exp. Farms Bul. 57, pt. 2, p. 37–51. 1907.

Wood, T. B. The Chemistry of strength of wheat flour. *In* Jour. Agr. Sci., v. 2, pt. 2, p. 139–159, 2 fig.; pt. 3, p. 267–277, pl. 5–6. 1907.

Baker, J. L., and Hulton, H. F. E. Considerations affecting the "strength" of wheat flours. *In* Jour. Soc. Chem. Indus., v. 27, no. 8, p. 368–376. 1908.

Willard, J. T., and Swanson, C. O. The baking qualities of flour as influenced by certain chemical substances, milling by-products and germination of the wheat. Kans. Agr. Exp. Sta. Bul. 190, p. 237–285, illus. 1913.

tion should also be made of durum wheat, which on the average has the highest crude protein of any wheat, but which is of only medium strength.

The wide difference between durum and common wheat in the relation between these factors has been mentioned. Some differences in the relation of crude protein to loaf volume or expansion are also observed with other classes of wheat. For a given percentage of protein the loaf volume is greater for hard red spring wheat than for either hard or soft red winter wheat and is greater for hard winter than for soft winter wheat. This is illustrated in figure 19.

PROTEIN CONTENT OF WHEAT AND FLOUR.

Since in baking flour is used rather than the wheat itself, it is of interest to note the relation between the protein content of flour and that of the wheat from which it is made. The data in Table V show the general variations to be expected, and it is evident that the protein content of the flour, as a rule, is considerably lower than that of the wheat, though in a small percentage of cases it appears to be slightly higher.

TABLE V.—*Relationship between the crude-protein content of wheat and that of straight flour produced from hard and soft red winter and hard red spring wheat of the crops from 1909 to 1913, inclusive.*

Crude protein in straight flour.	Proportion of samples falling into various ranges in crude-protein content of wheat (per cent).									
	8 to 8.9	9 to 9.9	10 to 10.9	11 to 11.9	12 to 12.9	13 to 13.9	14 to 14.9	15 to 15.9	16 to 16.9	17 to 17.9
Range (per cent):										
17 to 17.9	......	......	......	......	......	......	......	......	......	25
16 to 16.9	......	......	......	......	......	......	......	......	......	50
15 to 15.9	......	......	......	......	......	......	......	......	67	......
14 to 14.9	......	......	......	......	......	1.5	4.3	55.5	33	25
13 to 13.9	......	......	......	......	......	12.8	52.9	38.9	......	......
12 to 12.9	......	......	0.5	5.6	16.2	66.2	35.6	5.6	......	......
11 to 11.9	......	......	2.5	21	62.1	17.3	5.7	......	......	......
10 to 10.9	......	4.2	40	60.1	20.7	2.3	1.4	......	......	......
9 to 9.9	......	44.7	52	12.4	1	......	......	......	......	......
8 to 8.9	31.7	46.9	5	.9	......	......	......	......	......	......
7 to 7.9	68.3	4.2	......	......	......	......	......	......	......	......
Number of samples	19	47	203	224	203	133	70	36	3	4

Cases where the protein content of flour is higher than that of the wheat are evidently abnormal and are explained by the differences in the moisture content of the wheat and of the flour. A sample of wheat of unusually high moisture content might appear to have a low percentage of protein, while the flour having a moisture content several per cent lower might appear higher. This seeming inconsistency could be eliminated by calculating constituents to a dry basis, but this hardly seemed desirable, as it makes the interpretation of results more complex from a commercial standpoint.

The average protein content of the wheat and of the straight flour is compared in Table VI. With all three classes the protein in the flour averages about 1 per cent less than in the wheat.

TABLE VI.—*Average crude-protein content of three classes of wheat and of the straight flour made therefrom.*

Class of wheat.	Number of samples.	Crude protein (per cent).	
		Wheat.	Straight flour.
Soft red winter	215	10.6	9.6
Hard red winter	323	12.1	11.2
Hard red spring	394	12.9	11.9
Total or average	932	11.9	10.9

WATER ABSORPTION OF FLOUR.

The importance of the water-absorbing power of flour in its relation to bread-making quality has been mentioned. Figure 20 will emphasize what has been said of the connection of water absorption with the weight of the baked loaf. It will be observed that as the absorptive power increases there is a proportional increase in the weight of the loaf, due to the water retained in the bread during baking. That under average conditions the proportion of absorbed water retained remains practically constant is also shown diagrammatically in figure 20.

In figure 21 a comparison is made of the flour from the five classes of wheat under discussion, and it will be observed that the flour from the soft white wheat has the lowest average absorption, while the soft red winter wheat comes second. The hard wheat classes, including the durum, do not show any very great differences, although the hard red winter wheat averages slightly lower than the other two classes. The extreme range in water absorption is narrowest in the soft wheat and widest in the durums. There would seem to be a fairly close connection between the gluten content or crude protein and the absorptive power of flour, as will be seen by comparing figure 21 with figure 18.

SUMMARY.

(1) Normal, plump, dry, and sound wheat of all classes yields approximately the same percentage of flour. Over 80 per cent of the samples of each of the three classes of the more common wheats, soft and hard red winter and hard red spring, yielded between 67 and 75 per cent of flour.

(2) There is a direct relation between milling yield and the moisture content of wheat, and in a general way the yield varies inversely

with the moisture content. Were it possible to eliminate other factors, such as variation in plumpness of the kernels, it is probable that this relationship would be more apparent.

(3) The weight per 1,000 kernels or average weight of kernels has very little value in judging the potential flour yield.

(4) Although there are frequent exceptions when individual samples are considered, average results show a very striking relation between weight per bushel and flour yield, the latter varying directly as the former. The ratio between these two figures, however, is not quite the same for the different classes, nor is it the same for all varieties within each class.

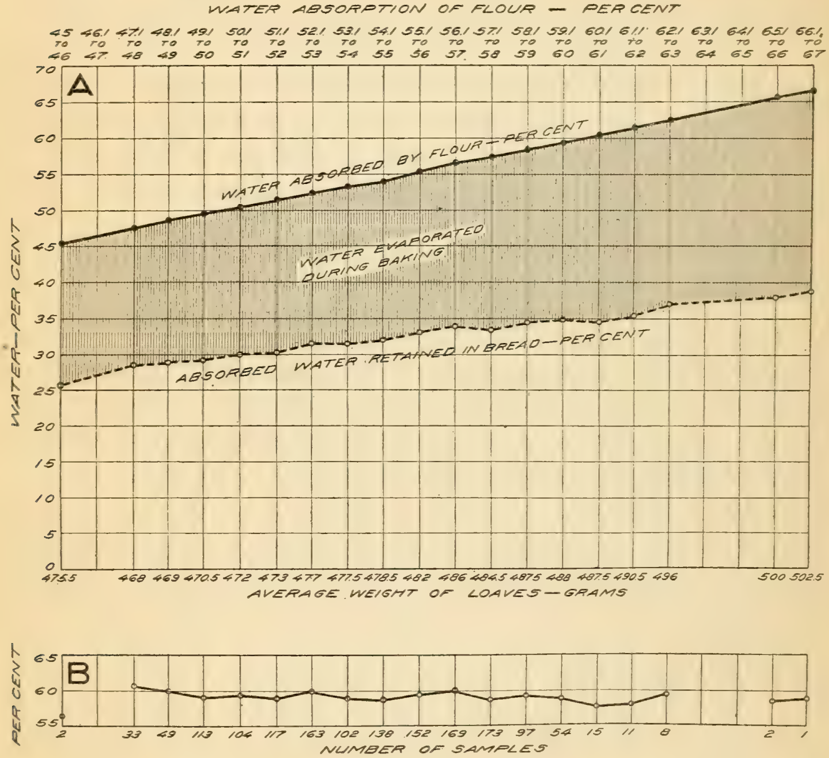

FIG. 20.—Diagram showing the relation between the water absorption of the flour and the total weight and water retention of the baked loaf. *A*, Comparison of water absorbed by the flour, water retained in the bread, the water evaporated during baking, and the weight of the baked loaves; *B*, curve showing the proportion of water absorbed by the flour which was retained during baking.

(5) In color the bread from the flour of the various classes of common wheat shows about the same ranges and averages. The flour from durum wheat is considerably more creamy and thus averages several points lower than that of any other class.

(6) Bread from all normal durum samples has a tinting or coloration, varying from slightly creamy to bright yellow, while of the hard red winter samples 77.6 per cent show a noticeable creamy tint; of the hard red spring samples, 69.5 per cent; and of the soft red winter samples only 18.9 per cent.

(7) The general results indicate that test weight and soundness, when considered together, are of far more value in appraising quality than when either is considered by itself.

(8) Small amounts of inseparable material are generally accompanied by a decrease in flour yield, as would be expected, in that as a rule a large part of such material usually finds its way into the bran and shorts.

(9) Loaf volume and texture are the two factors which are considered as indicative of strength. While a great range of strength was found within each class of wheat, the averages for each class show considerable differences between the various classes when considered as a whole. Given in order from weakest to strongest the classes are soft white, soft red winter, durum, hard red winter, and hard red spring wheat.

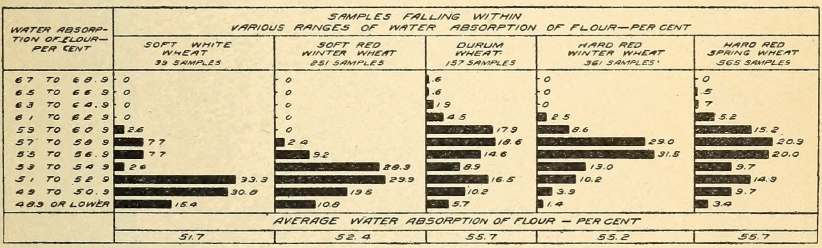

FIG. 21.—Diagram presenting a comparison of the water absorption of the flour of five classes of American-grown wheat, showing variation, general range, and average for each class. Samples from the crops of 1908 to 1913, inclusive.

(10) The average loaf volume in cubic centimeters for each of these classes is soft white wheat, 1,909; soft red winter, 1,965; durum, 2,070; hard red winter, 2,219; and hard red spring, 2,421. In the matter of texture the several classes stand in the same order, except that soft red winter has a slight advantage over durum wheat.

(11) Of the four more important classes of wheat under consideration, durum is the highest in crude-protein content; hard red spring, second; hard red winter, third; and soft red winter, fourth.

(12) High crude-protein content as a rule is accompanied by high strength, but the relation between these two factors varies with the different classes of wheat and extremely high crude-protein content is sometimes accompanied by a decrease in baking strength.

(13) The average water absorption of the flour from durum and from hard red spring wheat is about the same, and that of hard

red winter is only slightly lower. The water absorption of the soft wheats averages from 3 to 4 per cent lower than for the hard wheats. The range of water absorption of each class varies within wide limits.

(14) There is a direct relation between the water absorption of the flour and the bread yield of a unit quantity of the same. As a rule, the higher the absorption the greater the weight of the loaf.

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